50

Research Report

Modeling Scenarios for Water Allocation in the Gediz Basin, Turkey

Geoff Kite
Peter Droogers
Hammond Murray-Rust
Koos de Voogt

International Water Management Institute

Research Reports

IWMI's mission is to improve water and land resources management for food, livelihoods and nature. In serving this mission, IWMI concentrates on the integration of policies, technologies and management systems to achieve workable solutions to real problems–practical, relevant results in the field of irrigation and water and land resources.

The publications in this series cover a wide range of subjects-from computer modeling to experience with water users associations-and vary in content from directly applicable research to more basic studies, on which applied work ultimately depends. Some research reports are narrowly focused, analytical, and detailed empirical studies; others are wide-ranging and synthetic overviews of generic problems.

Although most of the reports are published by IWMI staff and their collaborators, we welcome contributions from others. Each report is reviewed internally by IWMI's own staff and Fellows, and by external reviewers. The reports are published and distributed both in hard copy and electronically (www.iwmi.org) and where possible all data and analyses will be available as separate downloadable files. Reports may be copied freely and cited with due acknowledgment.

Research Report 50

Modeling Scenarios for Water Allocation in the Gediz Basin, Turkey

Geoff Kite
Peter Droogers
Hammond Murray-Rust
and
Koos de Voogt

International Water Management Institute
P O Box 2075, Colombo, Sri Lanka

IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Pakistan, South Africa, and Sri Lanka.

This study was conducted as part of a collaborative research program between the General Directorate of Rural Services (GDRS) in Turkey and the International Water Management Institute (IWMI), and is partly funded by the Government of Turkey as part of the World Bank-assisted Turkish Agricultural Research Plan (TARP).

This report results from work carried out as part of a joint General Directorate of Rural Services (Government of Turkey)– IWMI study of the Gediz basin. The report was reviewed by Doug Merrey and Ian Makin and by two anonymous referees.

The authors: Geoff Kite and Peter Droogers are Hydrologists and Hammond Murray-Rust is Senior Irrigation Specialist, all of the International Water Management Institute, Colombo, Sri Lanka, and Koos de Voogt is a student of the Wageningen Agricultural University, the Netherlands.

Kite, Geoff, Peter Droogers, Hammond Murray-Rust, and Koos de Voogt. 2001. *Modeling scenarios for water allocation in the Gediz basin, Turkey.* Research Report 50. Colombo, Sri Lanka: International Water Management Institute.

/ water management / water allocation / models / river basins / hydrology / decision making / environmental protection / water use efficiency / climate / irrigation water / irrigated farming / streamflow / surface water / salt water intrusion /Turkey /

ISBN 92-9090-417-8

ISSN 1026-0862

Please direct inquiries and comments to: *iwmi-research-news@cgiar.org*

Contents

Summary

Hydrological models are able to simulate the natural processes involved in translating precipitation to runoff with a reasonable degree of success. When such models are extended to include the nonnatural processes such as dams, reservoirs, diversions and irrigation, then they may be used to simulate the water resources of a basin. Such a model may also be used to evaluate past water resources and to assess the effects of past management decisions. Lessons learnt from the past can be used to predict the impact of future changes in water management. Next, if we believe the model adequately describes the basin processes, we can use it with completely different sets of data to evaluate the effects of alternative conditions such as changed land use, changed climate or changed management decisions on the water resources. Finally, such a model can be used in conjunction with economic models to optimize water use within a basin under different external conditions.

This report describes the use of a distributed hydrologic model to evaluate different data scenarios for the Gediz basin in Turkey. The study attempted to answer questions such as; what will happen to the basin water resources if a) there is a change in climate, b) it is decided that more water must be retained in the river for environmental reasons c) more water is extracted for urban and industrial use, or d) the timing and amounts of water used for irrigation are changed? The effects of such changes were evaluated in terms of their impacts on the yields of irrigated agriculture and on the volume of water discharged at the outlet of the basin.

It was found that a climate change (the output from the UK Meteorological Office's Hadley atmospheric model was used) such as might occur with a doubling of carbon dioxide would have the largest impact of any of the scenarios studied. Average streamflows would decrease to about two-thirds of their current levels in a wet year, and by almost half in a dry year. Minimum flows would fall by roughly one quarter in both wet and dry years. This would have serious environmental implications because of damage to important wetlands and increased pollutant concentrations (the dilution effect). The other scenarios tested have much less impact at the basin level. At the irrigation scheme level, the greatest impacts result from the climate change scenario and from increasing the minimum base flow. The effects are felt more in the lower part of the basin and result in a much reduced supply of surface water. To compensate for this reduction there should be greater reliance on groundwater, which is already restricted in the lower part of the basin due to intrusion of salt water and poor water quality. The alternative would be to reduce the area irrigated.

At the field scale, climate change would reduce crop yields by nearly 9 percent in a wet year and by 11 percent in a dry year. Increasing the irrigation frequency and reducing the amount of water per application would increase yields of cotton and grapes by 19 percent and 7 percent, respectively, in a wet year. In a dry year, cotton yields would remain unchanged but grape yields would be 8 percent higher. Leaving the amount applied unchanged but increasing the interval between applications would make the cotton yield slightly higher in wet years and slightly lower in dry years. This indicates that farmers might consider modifying their irrigation practices, with more frequent but smaller applications for cotton and less frequent but larger applications for grapes.

Further scenarios could be used to investigate the effects of more efficient irrigation technologies such as precision land leveling, trickle irrigation or gated pipes. The approach is very flexible and could easily be applied to other basins.

Modeling Scenarios for Water Allocation in the Gediz Basin, Turkey

Geoff Kite, Peter Droogers, Hammond Murray-Rust, and Koos de Voogt

Modeling and Assessment of Changes in the Gediz Basin

Increasing competition for water requires tools and techniques to manage this natural resource carefully. The use of techniques such as Geographic Information Systems, relational databases, and Remotely Sensed observation methods, can be used to evaluate past water resources and to assess the effects of past management decisions. Lessons learnt from the past can be used to predict the impact of future changes in water management. These predictions are generally more qualitative but accurate quantitative predictions are necessary to determine the expected water scarcity. For such quantitative prediction, well-tested and developed simulation models can be used. This report describes such quantitative analyses of different scenarios based on multi-scale integrated modeling using the Gediz basin in Turkey as an example.

The Gediz river, around 275 km in length, drains an area of 17,220 km^2 and flows from east to west into the Aegean Sea just north of Izmir, Western Turkey. The river network is controlled by four main reservoirs, and four regulators are used for irrigation diversions. River-flows from the heavy winter precipitation are stored in the main Demirköprü reservoir for release over the summer irrigation period. Precipitation in the basin ranges from over 1,000 mm per year in the mountains to 500 mm per year near the Aegean coast. The total irrigated area in the basin is about 150,000 hectares. Crop production within the basin includes cotton, cereals, tobacco, and vegetables and fruits like grapes, olives, and melons. Other activities in the basin include textile factories, weaving, salt production, and leather works. Urban areas within the basin are expanding and groundwater is extracted to supply water to the city of Izmir, located just outside the basin to the south.

Kite and Droogers (2000) describe the development of hydrological models for the Gediz basin in western Turkey. Kite (1995) describes the SLURP basin-level hydrological model and Van Dam et al. (1997) describe the SWAP model used at both irrigation-scheme level and field level, and conclude with a description of how the models link together so that outputs from one model could be used as inputs to another. This enables to assess consequences of predicted changes in climate or management at the three different scales involved.

The main purpose of developing models is not merely to describe what is currently occurring but to make predictions about the future. If models have a sound root in physical science so that the processes involved are accurately depicted within the model, then it is possible to make predictions by using the models with different input scenarios.

While it is relatively simple to use models to study single issues or impacts, the full benefits of multi-scale models can best be realized by studying the full range of probable impacts of a course of action. There is, for example, little benefit in modeling if it focuses only on a single benefit while ignoring larger-scale losses in another area. However, by approaching modeling in a systematic way it is possible to simplify reality to the extent that major trends and changes can be predicted. It was decided to adopt the approach of modeling scenarios that not only reflected some of the current thinking concerning likely trends in water availability and water management (IWMI 2000) but also represented a generic set of solutions.

Development of Scenarios

The project adopted a three-stage approach in deciding what to model and how to model it. This involved identifying possible scenarios, discussing the perceived importance and relevance of the scenarios with concerned individuals and organizations, and developing a generic set of probable scenarios from these responses.

Scenario Identification

A wide range of scenarios, or topics for modeling, were identified through a process of unstructured discussions with managers, water users, policy makers and fellow researchers. Each participant was asked to identify three topics, which he or she perceived as significant in the Gediz basin, and these are summarized in table 1. The results of this process clearly indicate the diversity of issues of concern and also the strong preference of individuals within their own field of expertise. Issues range from major water allocation changes to complex procedures in field water management.

The topics identified highlight the problem that modelers face insofar as it is a daunting task to try to model impacts of scenarios at several different levels. Nevertheless, it is precisely this challenge that was inherent in the original design of the project.

Prioritization

Choosing between these different modeling topics was not easy. In many cases, researchers are guided by their own disciplinary biases, as are representatives from different organizations and agencies who tend to be concerned only with those issues that are within their immediate purview. Because no single agency has overall responsibility for basin-level water management, priorities tend to become diffused as a consequence.

Different agencies were approached to see if they could prioritize from the list generated in the first part of the exercise (table 1). A questionnaire was generated that synthesized the original 26 scenarios into 6 broader categories, and allowed for additional categories to be added if the respondents so wished. The questionnaire used is presented in table 2 from which it can be seen that the broader categories are groundwater extraction, reservoir operations, climate change, pollution, environmental protection, and changed water-management practices within irrigation systems.

This approach was not successful insofar as those who responded were only concerned with their immediate short-term concerns, and there was no real interest in attempting to look beyond the short term to view the basin problems in a wider context. Therefore, this approach was abandoned and an alternative one was adopted, based on the research team’s analysis of the issues raised in table 1.

TABLE 1.

Gediz basin water resource management: List of possible topics to be studied as scenario-analyses.

Operation of the Demirköprü reservoir for more power generation (1)
Changes to the operating rules of the Demirköprü reservoir (1)
Model water resources demand with predicted global warming scenarios (1)
Model climatological changes (3)
Changes to irrigation system management and operation to give more water use efficiency (1)
Analysis of changes in irrigation management in the short and medium term (1)
Introduce a minimum river flow requirement (1)
Model base river demand flows to compensate for increasing pollution levels from cities (1)
Maintain minimum flow in the Gediz river for environmental reasons (1)
Model impact of system rehabilitation (1)
Model impact of higher urban water return flows (1)
Model impact of increased urban water extraction (2)
Model reduction in share of total water resources for irrigation (1)
Model changes of water demand and/or needs of irrigation, urban and industry over time (1)
Model impacts of changing to subirrigation and pressurized irrigation systems (1)
Is it possible to irrigate more land with modern irrigation methods with increasing water demand from other users (domestic, industrial)? (1)
Changes resulting from decrease in agricultural land area taken over by industry (1)
Changes in cropping pattern (2)
Changes in cropping pattern and irrigation technology (1)
Changes in irrigation technology (2)
Model changes to irrigation demand by 40% change to drip irrigation (1)
Model changes if 25% of farmers use drip irrigation for grapes (1)
Model changes arising from the use of deficit irrigation (2)
Model changes if the cropping pattern changes (for example cotton area decreases), and canal water distribution and timing will change (1)
Model impact of changing groundwater abstraction by cities (2)
Model groundwater changes (1)

Note: Table 1 also gives the outcome from meeting on Friday 12 February 1999, to discuss modeling of possible scenarios for water resources development in the Gediz Basin. The numbers in brackets denote the number of people proposing that item, where each contributor was allowed to identify three topics. Number of participants was 33.

Categorization of the Nature of Possible Changes

In terms of water management within a basin there are not only opportunities for management of demand and supply but also requirements to respond to uncontrollable circumstances that affect both supply and demand. Figure 1 shows the decision-making process for selection of the scenarios used in this project.

In terms of changes in supply it was not considered useful to examine the impact of increased supply. The assessment of the research team is that current demand (1995–1999) for water is less than current supply and that any increase in supply will have few, if any, managerial implications. Further, there are few possibilities for large-scale water storage structures on the Gediz river itself, so the possibility of building new reservoirs was not modeled.

Decreased supplies can come from either normal fluctuations such as the 1989–1994 drought or from longer-term changes such as climate change or changes in land use. The response to decreases in supply must be by managing demand, and there are really only two alternative responses that are possible: reducing water use in a single consumption sector or more, or making longer-term changes in policies that allocate water from one sector to another.

Water reduction among sectors provides only limited options for policy change. It is inconceivable that significant reductions would be possible in urban and domestic water extractions in the foreseeable future. The combination of natural population increase, migration from the east to the west of Turkey, and increased per capita water consumption as a consequence of rising standards of living, all place greater pressure on urban water supply. Industrial demand both in Izmir and in the smaller towns and municipalities in the area has seen a steady increase as well and it is hard to see how this will decline. Eventually, stricter enforcement of environmental standards will mean that water allocations for environmental protection will become increasingly important. Therefore, it is only in the agriculture sector that there is any realistic prospect of decreasing consumption from current levels.

Similarly, specific policy choices dealing with changing water allocations between sectors is likely to result in decreased allocations for agriculture and increased allocations for the other two important sectors: urban/industrial demand, and environmental demand. The only other possibility is a voluntary reduction in agricultural water use by individuals but in practice this has the same impact as a reduction in allocations at sector level for irrigated agriculture.

To better understand what the implications of these different scenarios might be, the first step was to establish a baseline scenario against which the five other scenarios could be compared. As part of the process of development of the baseline scenario a set of established performance parameters were used to make it possible to compare the impacts of a scenario against the most favorable and least favorable conditions of the baseline scenario. These performance parameters look not only at hydrologic impacts but also at the estimated impact on production and productivity in the agriculture sector.

FIGURE 1.

Decision-making tree for scenario selection.

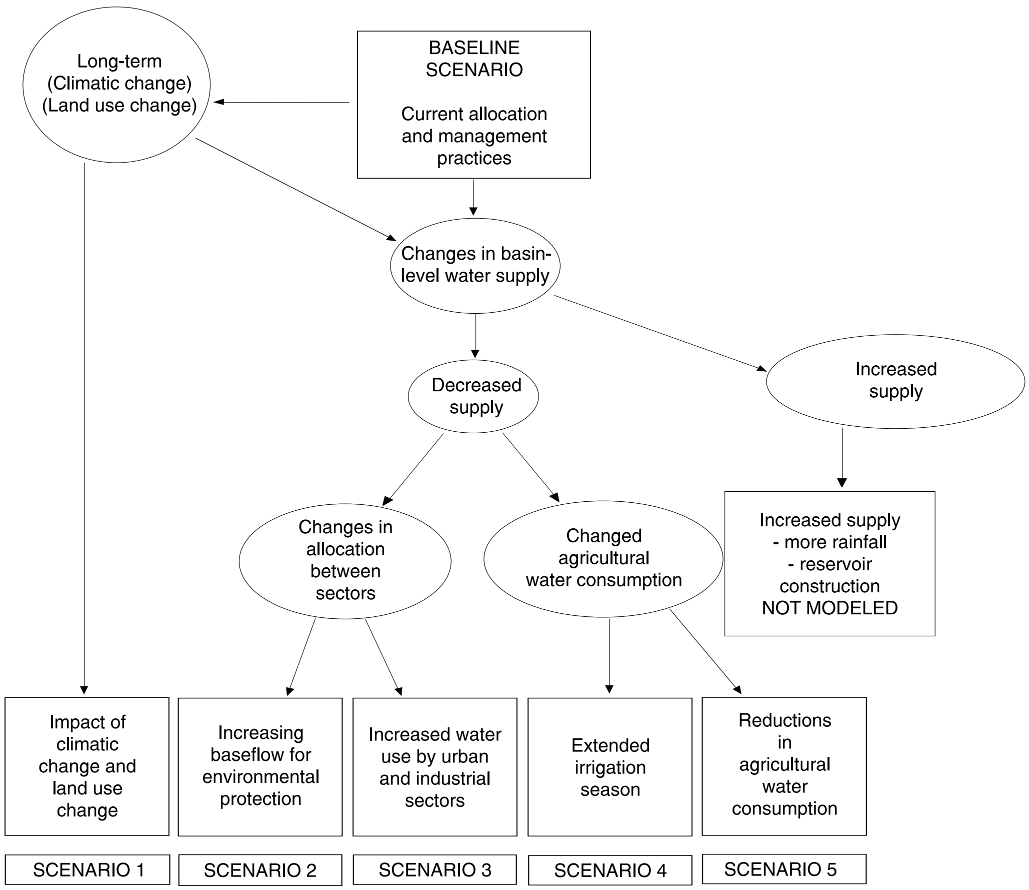


Table 2 presents a list of possible changes that might occur to the water resources of the Gediz basin over the next 20 years. The list is preliminary and has been prepared for discussion with agencies involved with water resources development within the basin.

It is intended to model 4–5 possible scenarios using the IWMI water resources model for the Gediz basin. The selection of the scenarios will be carried out following consultation with the various agencies involved in water resources development.

TABLE 2.

Gediz basin water resource management: Questionnaire on possible change scenarios.

For ……………………………………………………………….. the following are important:

---

q Model impacts arising from changes in groundwater abstraction
  - q abstraction for urban water supplies
  - q abstraction for irrigation

q Model impacts arising from changes to operation of the Demirköprü reservoir
  - q for power generation
  - q for other purposes

q Model climatological changes
  - q due to global warming
  - q due to regional trends

q Model impacts relating to river pollution
  - q changing levels of city and industrial pollution
  - q increased urban water return flows

q Model impacts of changes to protect/enhance the environment
  - q related to maintaining minimum river-flow levels

q Model impacts arising from changes in irrigation systems
  - q reduction in share of water available for irrigation
  - q changes in irrigation technology (e.g., from surface to drip irrigation systems)
  - q changes in cropping patterns
  - q changing irrigation water demand patterns
  - q increase in irrigated area
  - q reduction in irrigated area due to increased urbanization
  - q moves towards deficit irrigation
  - q changes arising from system rehabilitation
  - q changes in irrigation management to improve productivity and efficiency

Other areas of interest:

q

q

q

q

q

(Continue overleaf if necessary)

Development of the Baseline Scenario

The baseline scenario is derived from climatic, land use and management conditions in the Gediz basin from the period 1986–1998. It reflects a wide range of actual conditions, including the 1989–1994 drought as well as the wetter years before and after the drought. Table 3 shows the water balance over the entire basin, in mm, as recorded and as simulated by the hydrologic model for the period October 1, 1988, to September 30, 1998.

The net result of this process was the decision to model a few key scenarios that cover the majority of the realistic changes in the future. The scenarios selected, therefore, were:

- assessment of changes in overall supply, if any, through climate change
- maintaining base flow to meet environmental needs
- assessing the impact of increased urban/ industrial water withdrawals
- extending the irrigation season, while maintaining the same total quantity of water
- reductions in agricultural water consumption

The baseline scenario includes two extreme conditions that are particularly important because they enable the overall impacts of changes to be compared with conditions that are viewed as either particularly favorable or particularly unfavorable. These two extremes are:

- The most favorable condition is represented by outputs for 1997 when a) water supplies during the summer months were not limiting for irrigated agriculture, b) urban and domestic withdrawals could be met easily, and c) there were no complaints from the environmental lobby concerning the delivery of water to the wetlands in the delta that includes the Bird Paradise nature reserve.
- The worst condition occurred in 1992 when a) the drought was most severe, and only two releases could be made for irrigation during the entire summer, b) base flow from natural streams before and after the irrigation season was very low, c) water quality concerns were extremely high, and d) large parts of the Bird Paradise dried up with loss of much of the bird population, including representatives of endangered species.

TABLE 3.

The water balance (mm) as recorded and simulated by the hydrologic model, 1.10.1988–30.11.1998.

Basin precipitation	5.295E+03
Basin evapotranspiration demand	1.141E+04
Computed evaporation	9.695E+02
Computed transpiration	4.161E+03
Basin export/consumption from river	2.122E-01
Basin export/consumption from groundwater	4.017E+01
Computed runoff at basin outlet	2.368E+02
Change in water stored in the canopy	6.710E-01
Change in water stored in the soil	6.791E+00
Change in water stored as groundwater	-4.940E+01
Changes in reservoir storage	-7.075E+01
Irrigation taken from rivers	1.630E+02
Irrigation taken from groundwater	6.094E+00
Irrigation return flows to river	3.028E+01

By looking at a range of output indicators for these two extreme conditions it is possible to assess the changes in hydrology at basin, irrigation system, and field level under each scenario. Presumably, policy makers are concerned with options that alleviate the conditions experienced in 1992, and try to achieve the conditions experienced in 1997.

The baseline scenario describes the actual conditions experienced during this 13-year period. While results are available for all years, the focus is on the least favorable and most favorable conditions rather than describing a rather less-meaningful set of intermediate conditions.

Basin-Level Inputs and Outputs

The basin-level inputs reflect, as far as possible, the existing conditions experienced during the past 13 years. The main assumptions used for modeling conditions during this period are that:

- Water allocation decisions among sectors have remained the same, based on existing urban extractions within the basin and current arrangements for export of water to Izmir.
- The existing operational rules at Demirköpru have been applied.
- The irrigation system withdrawals of water at each regulator have been based on a consistent set of rules, and that discharges remain constant during each irrigation period.
- The physical configuration of reservoirs, control structures, and Aggregated Simulated Areas (ASAs, the basic simulation unit in the SLURP model; Kite 1995) has remained the same throughout the period.
- There has been no change in land cover in any part of the basin.
- The cropping pattern in major irrigation systems has remained unchanged.
- Each farmer attempts to apply 100 mm in each irrigation turn, and there is no proportional reduction to each farmer if supplies are limited. This reflects the conditions where head-end farmers can meet their full requirement and stress is focused on tail-end areas whenever there is a deficit in the total water supply.

Some of these assumptions are known to be imprecise. It is reported that there have been changes in land cover in the upper part of the basin, but the extent and impact are not known and cannot therefore be accurately represented in the model. There has been a shift from cotton to grapes in some parts of the basin during this period but because year-to-year changes are not known accurately the present cropping pattern has been assumed to be constant throughout the model period. Further, scenarios based on the current cropping pattern are likely to be more realistic than those based on an outdated cropping pattern. Another simplification in the model is the way water is distributed during water-short periods. Most Irrigation Associations try to spread water stress equally over their area, while the modeling conditions, as defined above, do not assume such a proportional reduction. However, such a proportional reduction will result, in most cases, in the tail-end areas getting stressed the most, as assumed by the model conditions.

Based on these baseline conditions the actual climatic data for the assessment period were used as the input and the resulting hydrology of the basin simulated. Outputs from the SLURP model include:

- estimated daily river flows at the lower boundary of each ASA and at the outlet of the Gediz river to the Aegean Sea
- daily water deliveries to each irrigation system
- estimated daily return flows from irrigation systems
- estimated daily evaporation
- estimated daily transpiration

Inputs and Outputs at Irrigation-System Level

The irrigation-level inputs include the total amount of water delivered to each irrigation system, the timing of any rotations, if any, the interval between each irrigation, and the depth of water applied. As far as possible, the exact conditions experienced in each year were included in the input files so that they reflect the actual management at system level.

The simulations at irrigation-system level were focused on the two main irrigation systems, Salihli Right Bank (SRB) and Menemen Left Bank (MLB). It is assumed that the combinations of soils and crops reflect conditions in other irrigation systems, and the results obtained through the simulations are transferable to other parts of the Gediz basin.

The performance of the irrigation schemes can be evaluated using performance indicators (Molden and Sakthivadivel 1999). Droogers and Kite (1999) give an example of such an evaluation, using model output. Here, it was decided to use the three following indicators from the nine defined by Molden et al. (1998):

- relative water supply (system-level water supply/actually consumed water)
- productivity of irrigation water in yield per volume of water applied (kg/m^3)
- productivity of irrigation water in gross revenues per volume of water applied (US$/$m^3$)

Other indicators have been defined, e.g., output per unit water consumed, and could be calculated using the results from the models developed. However, a more detailed analysis of the advantages and disadvantages of performance indicators is beyond the scope of this report and can be found elsewhere (e.g., Molden 1997; Molden et al. 1998).

The scenario modeling focused only on the most extreme conditions, with 1997 representing a wet year when water was not a constraint to crop production and 1992, which was the driest year for which data were available.

Field-Scale Inputs and Outputs

The field-level inputs used in the baseline scenario are comparatively simple, as the only management variables are the depth and frequency of irrigation applications:

- For 1997, it was assumed that all farmers had the opportunity for four full irrigation turns of 100 mm each, with an interval of 16 days between each irrigation turn during the peak requirement months of July and August.
- For 1992, the actual number of irrigation turns was reduced to two, again each of 100 mm, with an interval of 16 days between the two turns. These turns were in late July and early August, reflecting the actual situation at that time.

From the field-level data it is possible to determine four primary output parameters that can be used in the comparisons between the baseline scenario and other scenarios:

- estimated yield for the two main crops, cotton and grapes
- potential transpiration
- actual transpiration
- actual evaporation

A more detailed description of the methodology, the model, data requirements and outputs is beyond the scope of this report but can be found elsewhere (e.g., Droogers et al. 1999).

Scenario 1: Assessing the Impact of Climate Change

Many scientists are concerned about possible climate change induced by anthropogenically caused increases in greenhouse gases. Such a climate change would have major impacts on water resources and irrigated agriculture. To investigate this possibility, climate change data were obtained from the United Kingdom Meteorological Office atmospheric model (IPCC 1999). These data simulate average atmospheric conditions for the period 2010–2039 taking into account expected increases in greenhouse gases and sulphate emissions. For the area including the Gediz Basin the model predicts an average decrease in precipitation of 30 mm (a reduction of 5–10%) and an average increase in temperature of 1.9 ^{o}C.

These changes were included by adjusting the observed climatic data to reflect the decrease in precipitation and the increase in temperature. The same sequence of climatic events (i.e., rainfall, temperature, humidity, and radiation, wind speed) was maintained but their actual values were changed to accommodate the predicted decrease in rainfall and increase in temperature. This means that for the prediction for the wet year, the data for 1997 were adjusted to reflect conditions that would be expected if the climate change had already taken place. The data for the dry year, 1992, were adjusted in the same manner. The expectation that climate change will intensify extremes (wet years will be wetter and dry years will be dryer) was not taken into account, as this was not analyzed in the IPCC climate study.

The primary impacts of these assumptions in changes in rainfall and temperature will be a general reduction in water availability. The effect of decreased rainfall is made even more important because increased temperatures lead to increased transpiration by plants, and thus to an increase in crop water requirements.

There are a number of simplifications made in this analysis. No downscaling was carried out and general circulation model (GCM) data were used only as changes. An alternative approach to developing the data for this scenario would be to use the GCM data directly and to scale the data down from the GCM grid to the basin scale using a physical or statistical model.

Basin-level Impacts

The impact of these changes can be seen in terms of both point data at specified locations in the basin and areal data showing impacts across the whole basin.

The point data are best exemplified by hydrographs of river discharges at critical locations. The hydrograph in figure 2 shows the annual outflow from the Gediz basin into the Aegean Sea in wet years before and after climate change.

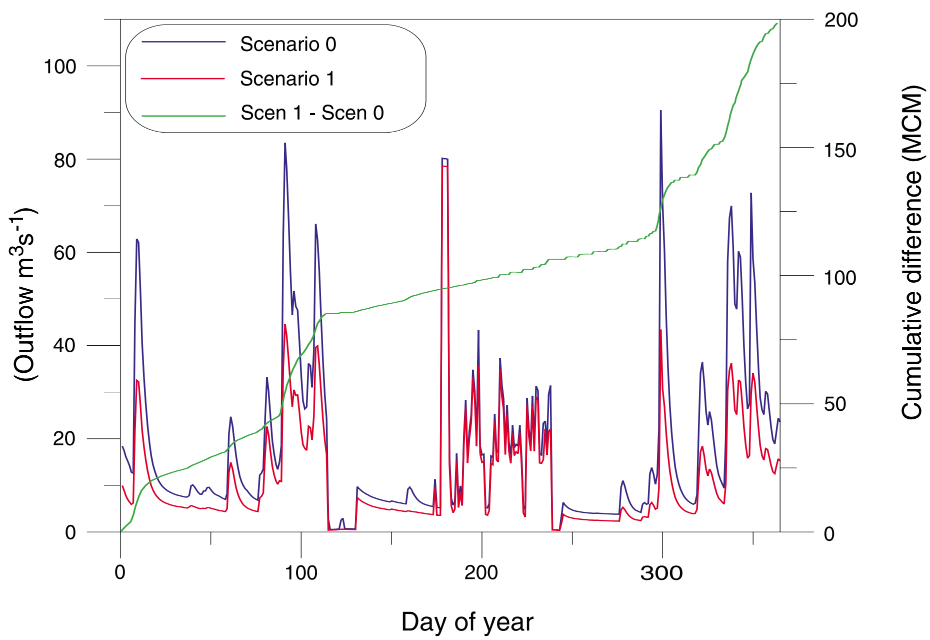
Simulations using actual climatic data for 1997 are compared with the simulations using the same basic data modified to show the effect of changed climatic conditions. There is an overall decrease of 35 percent in total discharge for the wet year while there is a decrease in both runoff peaks and base flow. This is a consequence of the reduction in average precipitation over the whole basin of 30 mm as well as an increase in transpiration due to the increase in temperature and an increased stomatal resistance of the crops during periods of water stress. Given that the impact of climate change in a wet year was that rainfall decreased by as little as 5 percent, a drop in 35 percent in total discharge reflects the impact of increased potential evaporation and transpiration on runoff and soil mosture storage.

In dry years, the simulation provides much more depressing results. Average annual runoff declines from 6.1 m^3s^{-1} in 1997to 3.3 m^3s^{-1} in the simulated dry year following climate change, a decrease of 46 percent.

Figure 3 shows that there is a general decrease of actual transpiration to be expected under conditions of climate change in the wet-year scenario. It is only in the mountainous areas with relatively higher precipitation that

FIGURE 2.

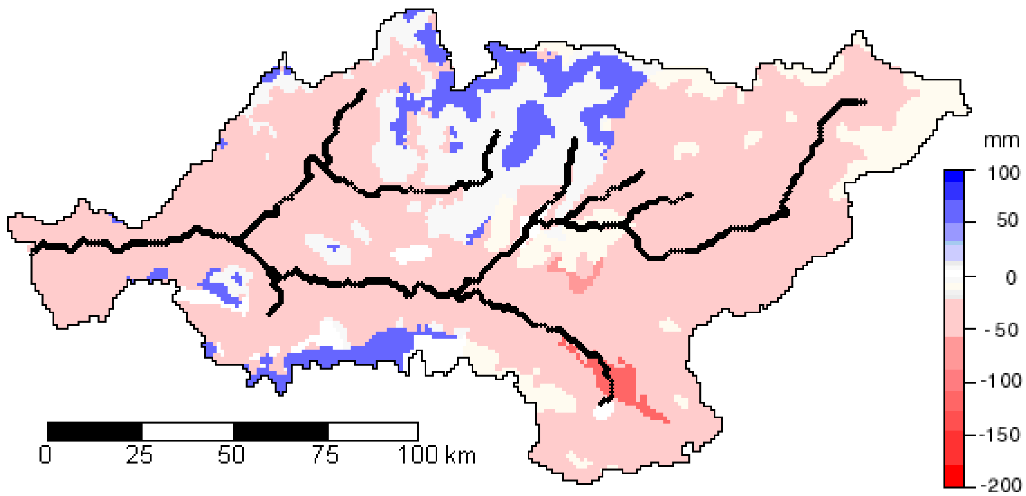
Changes in outflow from the Gediz river to the Aegean Sea following climate change.



Note: Scenario 0 = The base case; Scenario 1 = Change in climatic condition.

FIGURE 3.

Changes in actual transpiration, in mm, compared with the base scenario over the entire basin for the wet year.



there will be an increase in actual transpiration because there is sufficient moisture available for use by plants. In all other parts, actual transpiration will decrease because there is less water available, even though potential transpiration will be higher due to increased temperature. In drier years, actual transpiration is expected to decrease even more.

Field-scale

The impact of these climate changes on field-level conditions requires assumptions concerning the allocation of water between sectors or in water application practices as shown in figure 1. Assuming that the water allocation will be constant at field level, e.g., an increase or decrease in irrigated area but no change in allocation per field, SWAP analyses were performed to investigate yield, ET and soil moisture dynamics. No attempt was made to model the effect of increased CO_2 on crop growth, although this could be done by using the crop growth module included in the SWAP program (Van Diepen et al. 1989).

Potential transpiration increases as a result of higher temperature and lower humidity. This higher evaporative demand by the atmosphere requires a higher water availability for the crop in order to maintain crop yields. However, the predictions for Turkey in this climate-change scenario show a reduced amount of precipitation, increasing the crop stress even more. Yields will reduce by about 10–30 percent, compared to the base scenario (figure 4), even in the 1997 case where actual transpiration will go up by about 10 percent.

Potential transpiration and relative transpiration are plotted in figure 5 for grapes, in 1997. The relative transpiration is defined as the ratio of actual transpiration over potential transpiration and can be considered as a crop-stress characteristic. Clearly, for Scenario 1, crop stress was more severe in terms of quantity as well as in terms of duration. The two main reasons are the reduction in precipitation and increase in potential transpiration (figure 5, top).

FIGURE 4.

Changes in yield, actual crop transpiration (Tact) and actual soil evaporation (Eact) for Scenario 1, change in climatic conditions. Changes are related to Scenario 0, the base case.

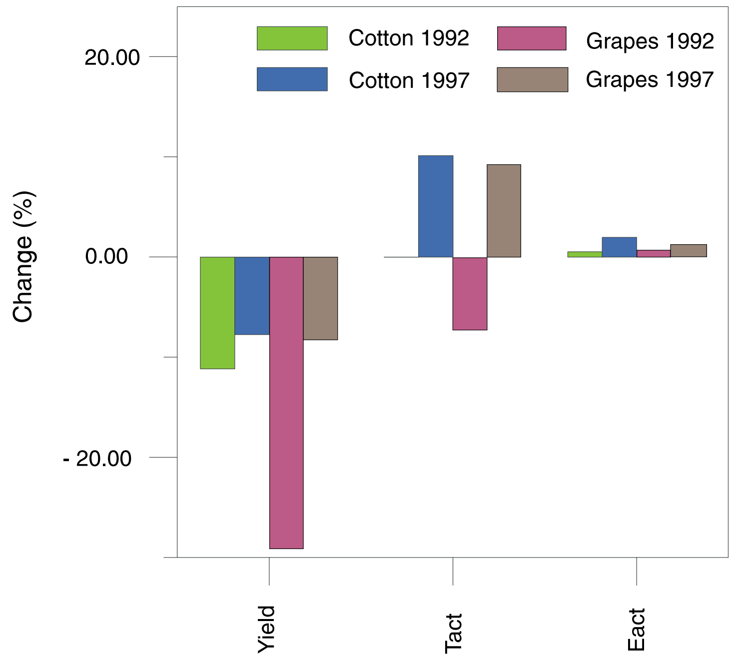
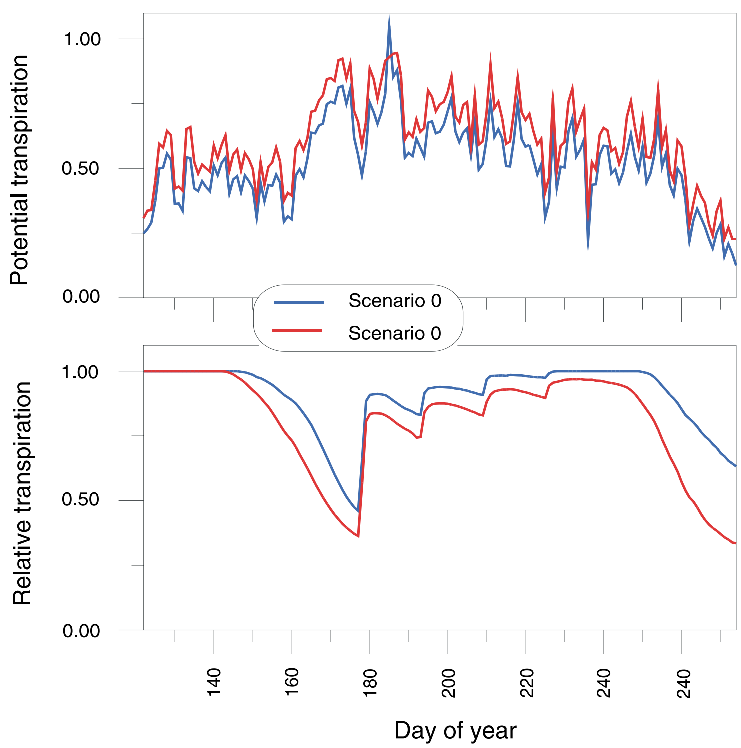


FIGURE 5.

Potential and relative transpiration for Scenario 0 and the climate change Scenario 1 for grapes in the wet year.



These changes have a major impact on the productivity of water. Potential transpiration goes up, with the consequence that actual transpiration would also go up, provided that water is available. With less water available, crop yields go down. In these results, other feedback mechanisms, such as a possible change in crop assimilation, are not taken into account and they would require more study.

Scenario 2: Sustaining Base Flow for Environmental Protection

Sustaining a critical base flow for environmental protection generally implies maintaining a minimum flow in the river for preservation of wetlands and for diluting pollution to acceptable levels. Part of the outflow of the Gediz river passes through the wetlands designated as the Kuş Cenneti bird sanctuary, before discharging to the Aegean Sea. The number and species of birds that visit the sanctuary are affected by the quantity and quality of the water in the reserve. A more detailed analysis and the water requirements of this bird sanctuary are described elsewhere (Voogt et al. 2000).

For the Gediz basin, detailed pollution modeling is not possible because data available are insufficient. While SLURP is capable of doing a simple pollution study it requires information on the total amount of pollutants entering the system, the location of the point sources where such pollution occurs, and details of any annual or seasonal fluctuations in the pollutant inputs. These data are lacking and it would only lead to confusion or contentiousness if arbitrary or assumed input values were used in this modeling activity.

The protection of wetland habitats can be approached in one of two ways. The first approach requires a detailed knowledge of the ecological requirements of different forms of wildlife during critical periods of the year, related to such factors as water depth, salinity and water quality. This information is not available and thus a detailed monthly management program cannot be developed that could be used as the basis for model studies.

The second, and simpler, approach is to make an overall assessment of total inflow requirements into the wetland. Because the key wetland habitat in the Gediz basin, Bird Paradise (Kuş Cenneti), is located close to the outfall from the Gediz basin to the sea, this can be done simply and quickly. The outputs for Scenario 2, therefore, are confined to estimations of the minimum flow requirements to the reserve. As detailed information about required water inflows to the bird sanctuary is lacking, it was assumed that the minimum required inflows have to meet the ET requirement of the 14,000-hectare wetland. This requirement is assumed to be 10 mm per day for midsummer and is equivalent to a flow of 16.2 $m^3 s^{-1}$ during this period.

This requirement is approximate because the actual ET depends on the temperature and the time of the year. As examples, it is possible that the reserve could manage with a lower base flow during the irrigation season because of excess water provided from the MLB irrigation scheme or perhaps the reserve could store water from higher flows earlier in the year. However, this storage capacity is limited, as water depth is a critical factor for birds.

For several months of the year, and certainly during winter months, there is ample water available for the Bird Paradise and there is no need for management intervention. The critical periods are before and after the irrigation season when releases are not made from the Demirköprü reservoir, and during the irrigation season when releases are designed to meet, only, irrigation requirements.

Table 4 lists the transpiration and Gediz river outflow under the baseline condition and Scenario 2 for the wet year and the dry year, assuming the peak requirement for the Bird Paradise to be 16.2 m^3/s^{-1}. As would be expected, the effect of a minimum base flow affects the dry year much more than a wet year. Under Scenario 2, MLB and Menemen Right Bank (MRB) irrigation schemes would receive only 6 percent less water, resulting in a 5 mm yr^{-1} reduction in transpiration for the wet year.

However, in dry years the diversions to the MLB and the MRB irrigation schemes might be reduced by 90 percent, from 18 to 1.8 $m^3 s^{-1}$ to make up the minimum flow into the Bird Paradise in the critical period that coincides with the irrigation season. It would be more equitable to distribute this shortfall among all of the six irrigation systems but there would still be a significant drop in production and productivity in the basin as a whole.

The hydrographs of the basin outlet in figure 6 show that the discharges under Scenarios 0 and 2 differ only for short periods of time during a wet year. Figure 6 also shows that before the irrigation season and between individual irrigation periods the discharge drops back to values considerably lower then 16.2 $m^3 s^{-1}$ at which the ET requirement is not met and the bird reserve might be endangered. To solve this, releases from the Demirköprü reservoir would have to be increased or less water diverted to upstream irrigation areas.

Given that the demand for water in the Bird Paradise competes directly with water stored in the Demirköprü reservoir for irrigation, it should be comparatively simple to include water allocations for environmental purposes in the seasonal water allocation decisions made for irrigation releases.

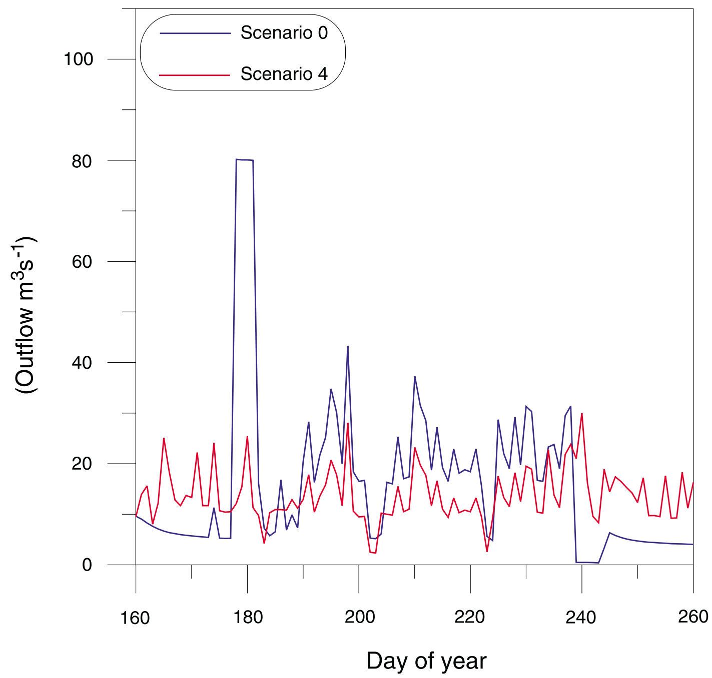
TABLE 4.

Change in average transpiration and basin outflow under Scenario 2.

	Transpiration (mm)			Outflow ($10^6 m^3$)		
	Baseline	Scenario 2	Change in %	Baseline	Scenario 2	Change in %
Dry year	365	236	-38	191	228	+19
Wet year	635	630	-1	573	608	+6

FIGURE 6.

Hydrograph of the basin outlet for a wet year under Scenarios 0 and 2.



Scenario 3: Increased Water Allocation for the Urban/Industrial Sector

The expected increase in population and rise in consumption due to increased prosperity will result in a substantial increase in urban and industrial water extractions. The estimated increase in population until the year 2020 for Gediz basin urban areas is 73 percent, from 2,798,000 to 4,846,000 (Municipality questionnaires collected by Water International Office, France). This increase in urban and industrial demand from 0.11 mm/day to 0.54 mm/day might affect the availability of water for irrigation and environmental purposes. In Scenario 3, the effect of this growing urban population on basin hydrology and the resulting increased water consumption were investigated.

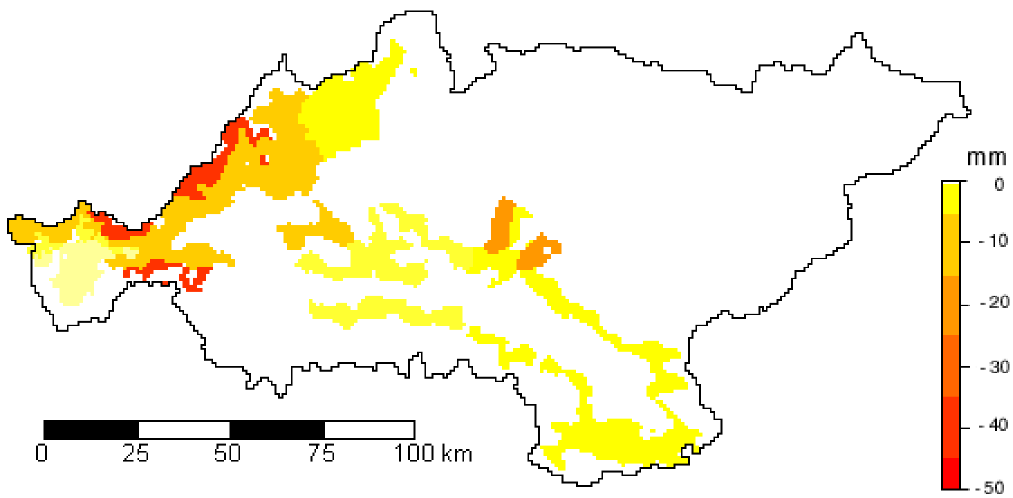
Surprisingly, the effect of this increased demand for urban and industrial extractions on the water balance of the entire basin is limited (table 6). The distribution of the effects is local and mainly affects the nonirrigated areas (figure 7). Irrigated areas are hardly affected as they rely mainly on surface water, while the urban withdrawals are mainly groundwater extractions.

Some of the affected areas may also have small-scale groundwater-based irrigation systems. Such systems would inevitably suffer if urban withdrawals are increased in terms of production due to reduced water availability and because groundwater levels will drop increasing pumping costs.

The interpretation of results from this scenario must be made with care because the representation of groundwater in the basin model, SLURP, simplifies the vertical water balance to a soil-water reservoir and a groundwater reservoir between which vertical movement takes place resulting in surface runoff, interflow and groundwater flow. In reality, groundwater extractions may involve several aquifers with movement of water between them. This scenario also did not include the effects of increased pollution levels resulting from increased urban return flows.

FIGURE 7.

Changes in actual transpiration, in mm, resulting from increased urban water withdrawals for a dry year.



Scenario 4: Using the Same Volume of Water over a Longer Time Interval for Irrigation

In the present situation, Scenario 0, the number of days of outflow from the Demiköprü reservoir and the corresponding diversions to irrigation schemes have all been determined by dividing the reservoir contents at the beginning of the irrigation season by the sum of daily water requirement for each canal system on the assumption that all canals are run full. This corresponds to the actual process used each year to determine the irrigation calendar.

If the canals were not run full, the irrigation season could be longer and this might change the productivity of irrigation water. In Scenario 4, the option of maintaining the allocation of the same volume of water for irrigation but spreading it out over a longer irrigation season was investigated. There are two ways in which this could be done.

In Scenario 4a, it was assumed that the irrigation interval does not change but that the amount of water applied per irrigation will be reduced. This reduction in the amount of water applied per turn may result in too small application depths for furrow irrigation, enforcing a switch to alternative delivery mechanisms. Therefore, in Scenario 4b, it was assumed that the interval between subsequent applications would increase, but that the amount of water applied per turn would remain the same as in Scenario 0, the base case. Only Scenario 4a was analyzed at the basin scale while Scenarios 4a and 4b were considered at the field scale.

Basin Level

In Scenario 4a, the reservoir releases were reduced so that the irrigation period could be maintained from June 10 to September 20 each year, instead of the current practice of an irrigation season starting on July 1 and ending on August 31. The diversions to each irrigation scheme and the application by furrow irrigation to each crop were reduced accordingly so that the total volume issued for the entire season remained the same.

For example, in 1998 the simulated outflows from the Demirköprü reservoir were reduced from 75 m^3s^{-1} to 53.9 m^3s^{-1}, the diversion to MLB irrigation scheme at Emiralem was reduced from 12 m^3s^{-1} to 8.0 m^3s^{-1} and the rate of application of furrow irrigation to cotton in the MLB irrigation scheme was reduced from 100 mm to 67 mm per application.

The effect of this extension of the irrigation season on the outflow from the Gediz basin is shown in figure 8. The total basin outflow under Scenario 4a is slightly lower than under current conditions and has reduced peaks. However, base flow at the outlet to the sea is higher in both June and September, a logical consequence of longer issue periods from the Demirköprü reservoir.

This reduction in range of outflow is emphasized in figure 9 by showing duration analyses of Gediz river outflows to the Aegean Sea for Scenarios 0 and 4a. In terms of irrigation productivity, such outflows during the irrigation season could be regarded as losses and a comparison of the flow duration analyses shows that during the irrigation period, under Scenario 4a less water is lost to the sea. However, these flows may have potential benefit for environmental protection.

FIGURE 8.

Hydrograph of the outlet-flow of the Gediz basin during the 1997 irrigation season (wet year) for Scenarios 0 and 4a.

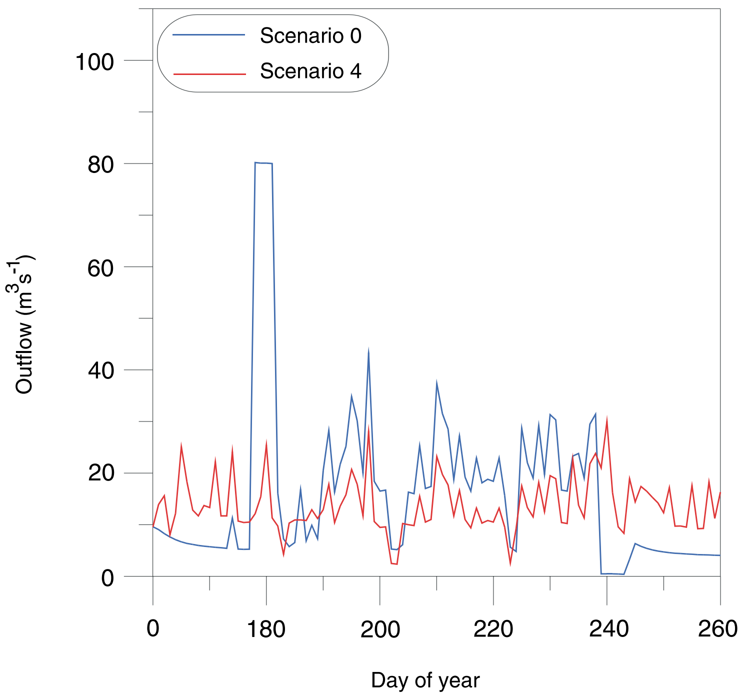


FIGURE 9.

Comparison of the flow duration curves in 1997 over the irrigation season for Scenarios 0 and 4a.

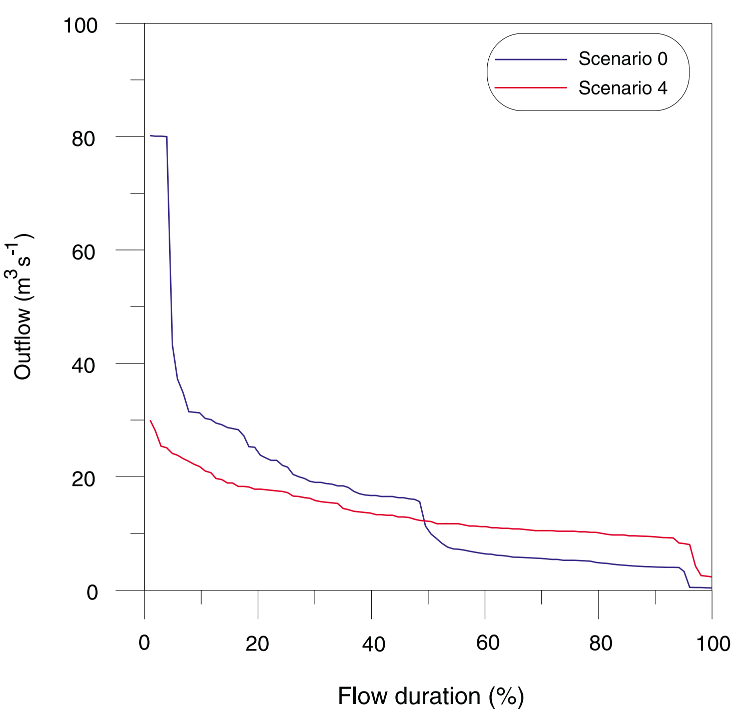


Figure 10 shows the relative difference in total irrigation-season crop transpiration across the Gediz basin between Scenarios 0 and 4a. Positive values mean an increase in the transpiration for Scenario 4a relative to Scenario 0. The map shows that crop transpiration will increase in the range from 0 to 10 percent, which indicates that extending the irrigation season could mean an increase in crop productivity.

Field Scale

The two sub-scenarios 4a and 4b defined as representative of possible extensions of the irrigation period were analyzed at the field level (table 5). Scenario 4a assumes an unchanged irrigation interval but a reduction in the amount of water applied per irrigation. Scenario 4b assumes that the interval between subsequent water applied will be unchanged. Both sub-scenarios assume that the total seasonal allocation of water for irrigation will be the same as in the base case, Scenario 0.

The effects of the two different scenarios are included in table 6. The general trend is that yields will be higher, while crop transpiration will be somewhat lower. This sounds somewhat contradictory, as crop transpiration and yield are linked to each other, but this results from the fact that the effect of water stress on crop development depends on the stage of crop growth. For Scenario 4a, less water over a longer period means that soil evaporation will be higher as the topsoil remains wetter for longer periods. In figures 11 and 12 the differences in yield, transpiration and evaporation between the two scenarios and the base scenario are expressed as percentages.

The SWAP model enables us to examine these differences in detail, by analyzing components of the water balance. For example, figure 13 shows the ratio of actual crop transpiration to potential transpiration for the three scenarios for cotton for a dry year.

For the base scenario, the crop starts to suffer from drought from day 160 (9th of June), while the first irrigation was applied only on day 200. For Scenario 4a irrigation water was distributed over 7 applications with a reduced depth per application. Clearly, after such a small irrigation application the soil water content was not refilled sufficiently to meet the full crop water requirements. For Scenario 4b the first day of stress was delayed due to the irrigation earlier in the season.

TABLE 5.

Irrigation input used in the SWAP analyses for MLB for the extended irrigation season scenario.

Year	Available water (mm)	Scenario 0 Int. (days)	Scenario 0 No.	Scenario 0 Depth (mm)	Scenario 4a Int. (days)	Scenario 4a No.	Scenario 4a Depth (mm)	Scenario 4b Int. (days)	Scenario 4b No.	Scenario 4b Depth (mm)
1992	200	16	2	100	16	7	30	50	2	100
1997	400	16	4	100	16	7	60	25	4	100

Note: Int. is the irrigation interval, and No. is the number of applications.

FIGURE 10.

Relative changes (%) in the annual transpiration in mm for 1997 (wet year).

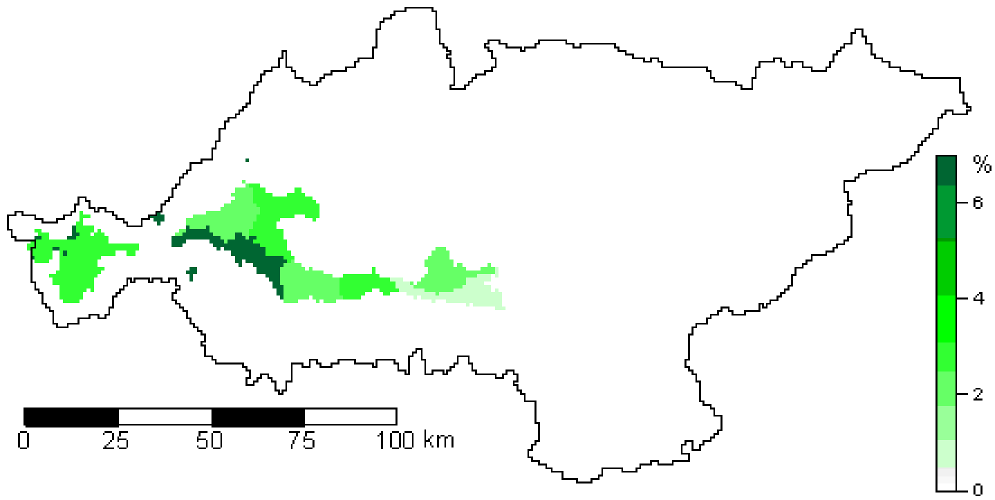


FIGURE 11.

Changes in yield, Tact and Eact for Scenario 4a, extending the irrigation season and reducing the depth of each application.

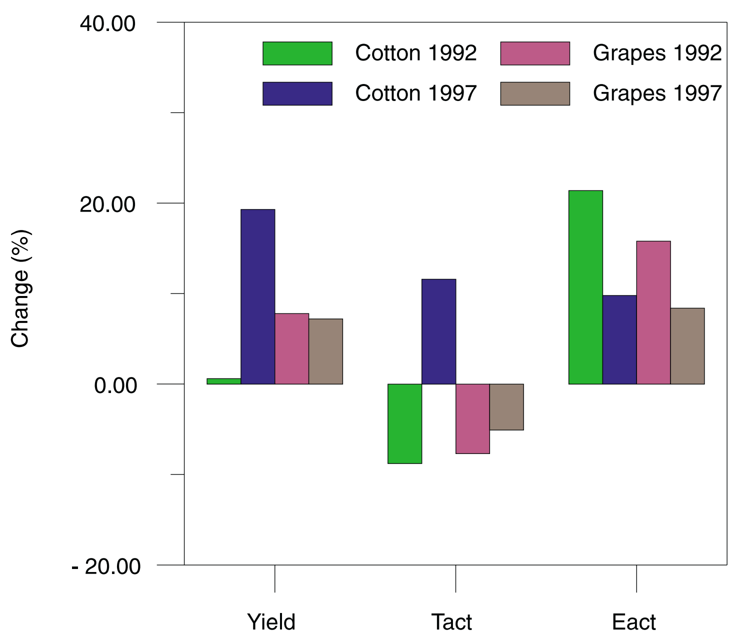


TABLE 6.

Results from the different scenarios for the three scales considered. Scenario 1 is climate change, Scenario 2 maintains a minimum base flow, Scenario 3 increases water allocation for urban and industrial use, Scenario 4 extends the irrigation season, and Scenario 5 uses less water for irrigation. The dry and wet years are 1992 and 1997, respectively.

	Baseline Scenario		Scenario 1		Scenario 2		Scenario 3		Scenario 4a		Scenario 4b		Scenario 5	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Basin level														
Mean Q ($m^3 s^{-1}$)	6.1	18.2	3.3	11.8	7.2	19.3	5.9	17.8	6.2	17.5	N/A	N/A	N/A	N/A
Min Q ($m^3 s^{-1}$)	0.04	0.4	0.03	0.3	1.8	3.7	0.04	0.4	0.1	0.5	N/A	N/A	N/A	N/A
Irrigation-system level														
RWS[1], MLB[2]	0.44	0.81	0.45	0.68	0.24	0.56	0.44	0.80	0.45	0.81	N/A	N/A	N/A	N/A
RWS, SRB[3]	0.22	0.40	0.29	0.42	0.22	0.40	0.22	0.40	0.21	0.45	N/A	N/A	N/A	N/A
Pwirr[2], MLB (kg m^{-3})	1.06	0.74	1.05	0.78	2.00	1.06	1.07	0.74	1.06	0.74	N/A	N/A	N/A	N/A
PWirr, SRB (kg m^{-3})	1.97	1.29	1.67	1.26	1.97	1.29	1.97	1.29	2.06	1.14	N/A	N/A	N/A	N/A
PWirr, MLB ($ m^{-3})	1.33	0.92	1.31	0.97	2.50	1.33	1.33	0.92	1.32	0.92	N/A	N/A	N/A	N/A
PWirr, SRB ($ m^{-3})	2.46	1.61	2.09	1.57	2.46	1.61	2.46	1.61	2.58	1.42	N/A	N/A	N/A	N/A
Field level														
Cotton														
Yield (kg ha^{-1})	1,620	2,739	1,439	2,527	N/A	N/A	N/A	N/A	1,629	3,268	1,508	2,860	1,080	2,040
Tpot[3] (mm y^{-1})	703	513	832	597	N/A	N/A	N/A	N/A	703	513	703	513	703	513
Tact[4] (mm y^{-1})	307	395	307	435	N/A	N/A	N/A	N/A	280	441	268	391	129	274
Eact[5] (mm y^{-1})	187	204	188	208	N/A	N/A	N/A	N/A	227	224	194	207	169	191
Grape														
Yield (kg ha^{-1})	3,316	4,193	2,350	3,846	N/A	N/A	N/A	N/A	3,576	4,495	3,838	4,630	3,090	3,609
Tpot (mm y^{-1})	1,056	859	1,277	1,031	N/A	N/A	N/A	N/A	1,056	859	1056	859	1,056	859
Tact (mm y^{-1})	684	782	635	854	N/A	N/A	N/A	N/A	631	742	647	779	462	620
Eact(mm y^{-1})	146	154	147	156	N/A	N/A	N/A	N/A	169	167	147	156	134	148

[1]RWS is relative water supply defined as the ratio of the irrigation applied to the crop transpiration.

[2]PWirr is the crop productivity per cubic meter of water applied.

[3]Tpot is potential crop transpiration.

[4T]Tact is actual crop transpiration.

[5]Eact is actual soil evaporation.

N/A is not applicable for the given scenario-scale combination.

FIGURE 12.

Changes in yield, Tact and Eact for Scenario 4b, extending the irrigation season while retaining the irrigation depths.

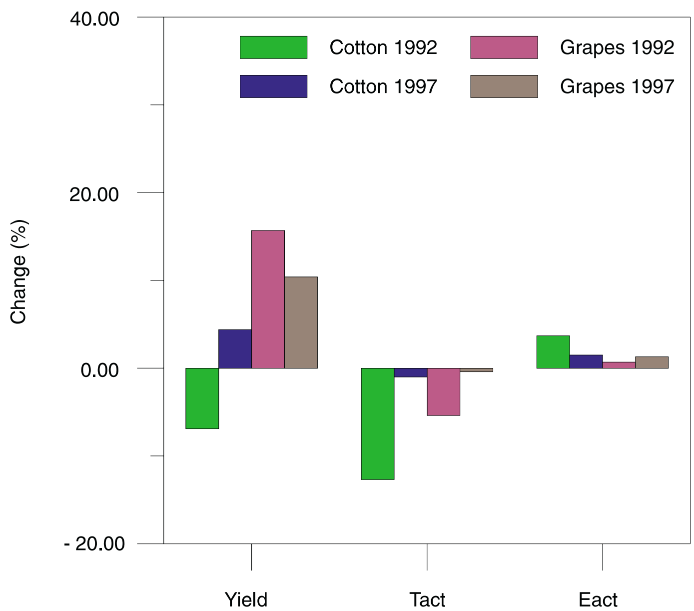
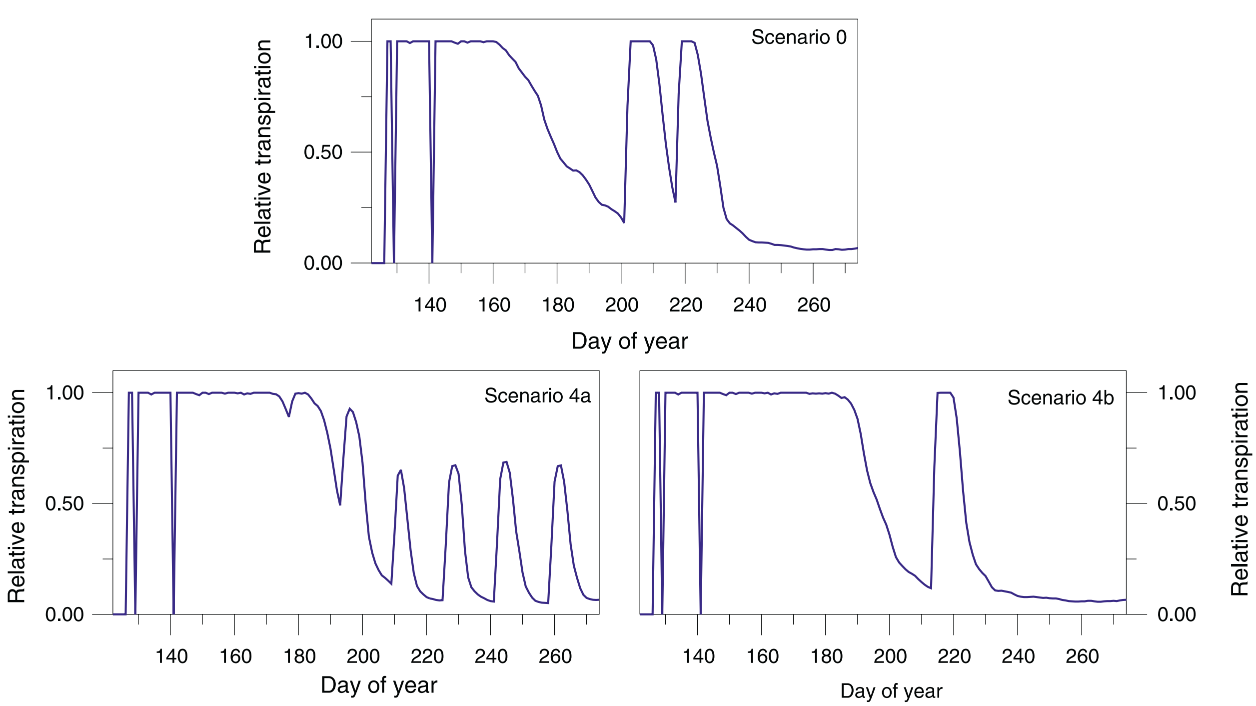


FIGURE 13.

Relative transpiration defined as the ratio of Tact to Tpot, for cotton in a dry year.

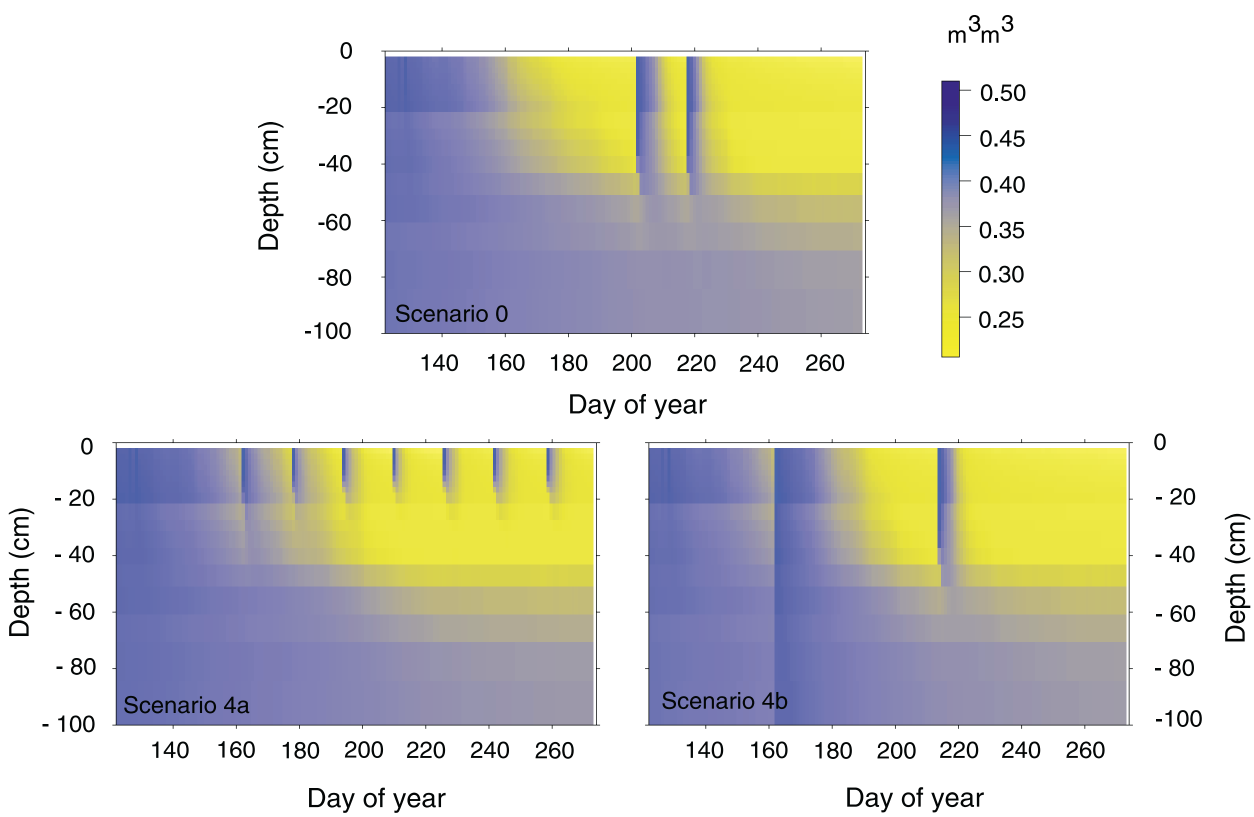


From figure 14 these differences in relative transpiration can be explained in more detail by showing soil moisture contents for the three scenarios during the growing season. The irrigation applications can be seen as wetting the soil (blue areas) while the dry parts of the soil show as yellow areas. Scenario 4a shows that the distribution of irrigation is better than the base case, but also indicates that the irrigation affects only the top 20 cm of the soil. The first irrigation of Scenario 4b is clearly too early and much of the water applied will flow to groundwater. For cotton, it is recommended to extend the irrigation period at the end of the season rather than at the beginning since, at the beginning of the season, the plant is not using much water and any irrigation will flow to groundwater.

Similar graphs can be drawn for the grape crop. The soil moisture profiles for grapes would show that the distribution of the scarce water in the case of Scenario 0 is not satisfactory. Scenario 4a shows a much better distribution, but only the topsoil will benefit from this, also inducing higher soil evaporation. Scenario 4b is therefore preferable with a better water distribution and a negligible increase in soil evaporation.

FIGURE 14.

Soil moisture contents for Scenario 4 compared to Scenario 0 for cotton in a dry year.



Scenario 5: Using Less Water for Agriculture

A likely scenario is that increased competition between different water users will result in a decrease in water availability for irrigated agriculture. The impact of this reduction has been analyzed at the field scale using the SWAP model. Instead of focusing on a dry and a wet year, a period of 30 years of historical weather data was used. The assumption is that these 30 years will represent the probable future weather conditions. This allows us to produce not only a single average value, but also to estimate the expected variability in yields as a consequence of the expected range in weather conditions. A typical cotton and grape crop in MLB irrigation scheme was selected for analysis.

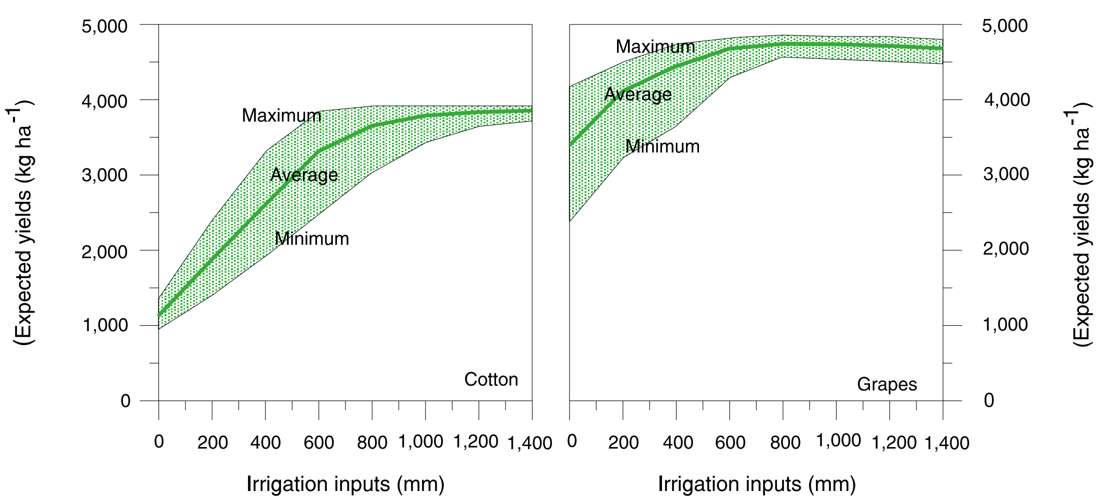
Figure 15 shows the average expected yields for cotton and grapes at different total irrigation applications. It is clear that with low amounts of irrigation grapes give higher yields than cotton. Grapes have a better-developed rooting system, which enables them to exploit both water stored in the root zone and capillary rise. It is also obvious from the graph that the optimal irrigation input for grapes is about 600 mm and for cotton about 800 mm. Higher irrigation inputs will not significantly increase yields.

The predicted yield ranges are also displayed in figure 15. The ranges in yields of cotton and grape show different patterns. The range is highest for grapes at low irrigation inputs, while it is highest for cotton at intermediate levels of irrigation input. For cotton, with a less-developed rooting system, yields are always low at low levels of irrigation input, while for grapes, with better-developed roots, a wet spring can increase yields substantially, even at low irrigation inputs.

To compare these results with those of other scenarios it was assumed that the amount of water available for irrigation was 200 mm less than for the base scenario. The results show that reduction of irrigation has a substantial effect on crop yields, especially for cotton (table 6).

FIGURE 15.

Expected yields, given a certain amount of water available for irrigation. Average, minimum and maximum yields are shown.



Comparison of the Results of Different Scenarios

Table 6 shows the results from the different scenarios in quantitative form for the key parameters at all three spatial scales. For each scenario, results are given for the dry year (based on 1992 conditions) and the wet year (based on 1997 conditions). Given that a typical dry year is established early in the year as a result of poor winter rains, water allocation decisions made in March or April will be able to take into account actual water conditions. The data presented enable the implications of different scenarios to be compared and provide a simple way for decision makers to evaluate policy options.

Parameters Used for Comparison

At *basin level* two parameters have been used to compare the different scenarios. The mean discharge represents the total annual surplus flowing out of the Gediz into the Aegean Sea, most of the runoff during the winter months originating from the basin downstream of the Demirköprü reservoir. The minimum discharge is important for two reasons: it indicates whether the basin is closing (i.e., all water is used before it reaches the sea), and it indicates the likely severity of agricultural, urban, and environmental concerns in terms of water quantity and quality.

At *irrigation-system level* the indicators used were relative water supply and productivity of water. Relative water supply calculations for this study compare irrigation releases with total crop transpiration. Because transpiration is calculated for the whole season while irrigation is concentrated into about 2 months, and because rainfall, soil moisture storage and changes in groundwater storage are not included in the supply of water, relative water supply values are low. However, in the context of this study, the important element is the extent to which they change from one scenario to another.

The productivity indicators look at gross returns per cubic meter of irrigation water supplied, both in terms of yield (kg/m^3 of irrigation water) and value (US$/$m^3$ of irrigation water). Net productivity of water requires detailed analyses of input costs and these have not been included in this study.

The data have been calculated for an upstream system (SRB) and a downstream system (MLB) to determine if there are differences in the impacts of the various scenarios within the basin.

At *field scale* the analysis compares predicted cotton and grape yields, potential transpiration and actual transpiration, and actual evaporation.

Basin-Level Impacts

In terms of overall basin conditions, climate change has by far the greatest impact if current management practices and water allocations are maintained. Average flows decrease to about two- thirds of their current levels in a wet year, and by almost half in a dry year. The runoff from the basin in a wet year, currently at 33.8 mm/year, drops to 21.9 mm/year, while dry-year runoff falls from 11.3 mm/year to 6.1 mm/year.

Minimum flows fall by roughly one quarter in both wet years and dry years, with virtually no flow in dry years. This has serious environmental implications not only because the wetlands will continue to be damaged in such dry conditions but also because pollutant concentrations will be even higher than current levels.

The other scenarios have much less impact at basin level. If efforts are made to increase base flow, then both basin yield and minimum flows increase. The average discharge from the basin increases by approximately 1.1 m^3s^{-1} in both wet years and dry years, or annual increases of 6 percent and 18 percent, respectively. Minimum flows, as would be expected, increase dramatically to 3.7 m^3s^{-1} in wet years and 1.8 m^3s^{-1} in dry years.

The increase in urban water extraction has no significant impact compared to present conditions. This is because urban water extractions remain small compared to agricultural use, and making changes in the way irrigation water is allocated and managed does not have much impact on total depletions or on return flows from irrigation schemes.

Impacts at Irrigation-System Level

In terms of relative water supply the greatest impact comes from climate change (Scenario 1) and increasing minimum base flow (Scenario 2). The effects are felt more in the lower part of the basin than in Salihli and result in a much lower relative water supply. This means that, to compensate for the reduction in surface water supplies there would have to be more reliance on groundwater, which is already restricted in the delta due to the intrusion of salt water and poor water quality. The alternative is to reduce the area irrigated.

The effect on the productivity of water is also mainly restricted to the lower part of the basin, but the trend is reverse: lower relative water supplies are associated with higher productivity of water.

The other scenarios have very little impact on conditions at irrigation system level although productivity values decline slightly for Scenario 4 (extended irrigation season) because water is not used as efficiently by the plants.

Field-Scale Impacts

At the field scale, we compare crop yields for the different scenarios. Climate change will reduce crop yields, as precipitation will be lower and potential evaporative demand will increase. The effect is to reduce current yields by nearly 9 percent in a wet year and by 11 percent in a dry year.

Extending the irrigation season has a positive effect on yields. Scenario 4a, reducing the irrigation depth and increasing the frequency for cotton, is preferable to Scenario 4b. In Scenario 4a, wet-year- predicted cotton yields increase by 19 percent while grape yields increase by 7 percent. In dry years, cotton yields remain unchanged but grape yields increase by 8 percent.

For Scenario 4b, cotton yields in wet years are slightly higher than at present, but dry-year yields are lower. However, this scenario results in the highest grape yield in both wet and dry years.

This indicates that farmers might consider modifying their irrigation practices, with more frequent but smaller applications for cotton and less frequent but larger applications for grapes. An economic analysis should reveal whether this is a profitable option.

Finally, a decrease in irrigation inputs from 500 mm/season to 300 mm/season (Scenario 5) will reduce the expected yields, with cotton suffering more from this effect than grapes. Cotton yields would fall by approximately 25 percent in a wet year and 33 percent in a dry year, while grape yields would drop by 14 percent in wet years and 7 percent in dry years.

Conclusion

The scenarios described here have been easily and quickly analyzed by using the various scales of models, given the fact that models were already developed and tested. The existing models and datasets can also be used to define and explore an unlimited number of other scenarios. While the scenarios here have been selected to represent the most likely changes, it would be easy to modify the scenarios and evaluate their impacts.

The advantage of the approach adopted here is that it is not difficult to compare different alternatives and see which ones will be most likely to be acceptable to different users of water. It appears that, apart from Scenario 1, which cannot be controlled, efforts to save water can result in continued irrigated agriculture with high yields and productivity. This suggests that there are still possibilities for maintaining high overall output from the basin without the agriculture sector losing out. However, this will only be accomplished if farmers continue to invest in water-saving techniques and continue to move towards more efficient irrigation technologies such as precision land leveling, trickle irrigation and gated pipes.

Literature Cited

Droogers, P.; W. G. M. Bastiaanssen; M. Beyazgül; Y. Kayam; G. W. Kite; and H. Murray-Rust. 1999. Agro-hydrological analyses of an irrigation system in Western Turkey using simulation modeling. *Agricultural Water Management* (in press).

Droogers, P.; and G. Kite. 1999. Water productivity from integrated basin modeling. *Irrigation and Drainage Systems* 13: 275–290.

International Water Management Institute (IWMI). 2000. http://www.cgiar.org/iwmi.

IPCC. 1999. http:/ipcc-ddc.cru.uea.ac.uk/cru_data.

Kite, G.W. 1995. The SLURO model. Chap. 15 in *Computer models of watershed hydrology,* ed. V. P. Singh, 521–562. Colorado, USA: Water Resources Publications.

Kite, G. W.; and P. Droogers. 2000. *Integrated basin modeling.* Research Report 43. Colombo, Sri Lanka: International Water Management Institute.

Molden, D. 1997. *Accounting for water use and productivity.* SWIM Paper 1. Colombo, Sri Lanka: International Irrigation Management Institute.

Molden, D.; and R. Sakthivadivel. 1999. Water accounting to assess use and productivity of water. *Water Resources Development* 15: 55–71.

Molden, D.; R. Sakthivadivel; C. J. Perry; C. de Fraiture; and W. H. Kloezen. 1998. *Indicators for comparing performance indicators of irrigated agricultural systems*. Research Report 20. Colombo, Sri Lanka: International Water Management Institute.

Van Dam, J. C.; J. Huygen; J. G. Wesseling; R. A. Feddes; P. Kabat; P. E. V. VanWalsum; P. Groenendijk; and C. A. van Diepen. 1997. *Theory of SWAP version 2.0*. Technical Document 45. Netherlands: Wageningen Agricultural University and DLO Winand Staring Centre.

Van Diepen, C. A.; J. Wolf; H. Van Keulen; and C. Rappoldt. 1989. WOFOST: A simulation model of crop production. *Soil Use and Management* 5:16–25.

Voogt, de K.; G. Kite; P. Droogers; and H. Murray-Rust. 2000. Modelling water allocation between a wetland and irrigated agriculture in the Gediz Basin, Turkey. *Water Resources Development* (in press).

Postal Address
P O Box 2075
Colombo
Sri Lanka

Location:
127, Sunil Mawatha
Pelawatte
Battaramulla
Sri Lanka

Tel:
+94-1-867404

Fax:
+94-1-866854

E-mail:
iwmi@cgiar.org

Website:
http://www.iwmi.org

INTERNATIONAL WATER MANAGEMENT INSTITUTE

FUTURE HARVEST
IWMI is a Future Harvest Center
Supported by the CGIAR

ISSN 1026-0862
ISBN 92-9090-417-8

Research Reports

37. *Farmer-Based Financing of Operations in the Niger Valley Irrigation Schemes.* Charles L. Abernethy, Hilmy Sally, Kurt Lonsway, and Chégou Maman, 2000.

38. *An Assessment of the Small-Scale Irrigation Management Turnover Program in Indonesia.* Douglas L. Vermillion, Madar Samad, Suprodjo Pusposutardjo, Sigit S. Arif, and Saiful Rochdyanto, 2000.

39. *Water Scarcity and the Role of Storage in Development.* Andrew Keller, R. Sakthivadivel, and David Seckler, 2000.

40. *Using Datasets from the Internet for Hydrological Modeling: An Example from the Küçük Menderes Basin, Turkey.* Martin Lacroix, Geoff Kite, and Peter Droogers, 2000.

41. *Urban-Wastewater Reuse for Crop Production in the Water-Short Guanajuato River Basin, Mexico.* Christopher A. Scott, J. Antonio Zarazúa, and Gilbert Levine, 2000.

42. *Comparison of Actual Evapotranspiration from Satellites, Hydrological Models and Field Data.* Geoff Kite and Peter Droogers, 2000.

43. *Integrated Basin Modeling.* Geoff Kite and Peter Droogers, 2000.

44. *Productivity and Performance of Irrigated Wheat Farms across Canal Commands in the Lower Indus Basin.* Intizar Hussain, Fuard Marikar, and Waqar Jehangir, 2000.

45. *Pedaling out of Poverty: Social Impact of a Manual Irrigation Technology in South Asia.* Tushaar Shah, M. Alam, M. Dinesh Kumar, R. K. Nagar, and Mahendra Singh. 2000.

46. *Using Remote Sensing Techniques to Evaluate Lining Efficacy of Watercourses.* R. Sakthivadivel, Upali A. Amarasinghe, and S. Thiruvengadachari. 2000.

47. *Alternate Wet Dry Irrigation in Rice Cultivation: Saving Water and Controlling Malaria and Japanese Encephalitis?* Wim van der Hoek R. Sakthivadivel, Melanie Renshaw, John B. Silver, Martin H. Birley, and Flemming Konradsen. 2000.

48. *Predicting Water Availability in Irrigation Tank Cascade Systems: The CASCADE Water Balance Model.* C. J. Jayatilaka, R. Sakthivadivel, Y. Shinogi, I. W. Makin and P. Witharana. 2000.

49. *Basin-Level Use and Productivity of Water: Examples from South Asia.* David Molden, R. Sakthivadivel, and Zaigham Habib. 2000.

50. *Modeling Scenarios for Water Allocation in the Gediz Basin, Turkey.* Geoff Kite, Peter Droogers, Hammond Murray-Rust, and Koos de Voogt. 2001.